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Subcontract NP-1

WANL-TME-1781
April 1968

Westinghouse Astronuclear Laboratory

WESTINGHOUSE ASTRONUCLEAR LABORATORY CONTRIBUTION TO THE TWENTY-SIXTH HIGH TEMPERATURE FUELS COMMITTEE MEETING

APRIL 30 - MAY 1 AND 2, 1968

MASTER

(Title Unclassified)

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SPECIAL REVIEW FINAL DETERMINATION	Reviewers		Class.	Date
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L. R. Fleischer

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1.0 INTRODUCTION

(U) The sixth reactor of the NERVA series, NRX-A6, was tested at NRDS in December, 1967. This was the fifth NERVA reactor tested under nuclear power and was the most successful.

(U) The NRX-A6 core has been disassembled and its components examined. The resulting raw data are currently being processed and analyzed. This report is a preliminary assessment of the test results indicated by these data.

(CRD) The reactor operated at full design power for more than 60 minutes. The exit gas temperature was on the order of 2050°C, and the average temperature of the gas at the fuel element exits was in the range 2130°C to 2290°C. During this operation the reactivity loss from the core was 65 ¢ (a drum rotation of 11 degrees), indicating a great decrease in corrosion loss over previous test cores.

2.0 TEST OBJECTIVES

(U) From the point of view of fuel performance, the general test objectives were as follows:

1) To operate at rated conditions for a total time of 60 minutes.
2) To evaluate the effects of 60 minutes of full power operation on the structural integrity of the core.
3) To evaluate the nuclear, thermal, and fluid flow performance of the reactor.

All test objectives were met.

(CRD) The most significant information coming from the test was the indication of greatly improved fuel capability. The combination of improved fuel coating techniques, dimensional control, attention to relative thermal expansion rates, flattened core power distribution, and changes in core interstitial pressure distribution resulted in marked improvements in core corrosion performance. In particular, the improved performance with respect to coolant channel corrosion resistance, primarily in the mid-band region, has resulted in elements capable of 60-minute, one-cycle operation at exit gas temperatures up to 2190°C with weight losses averaging about 13 grams per fuel element.

(U) In addition, comparison of quality control and other parametric, electrically powered corrosion tests of NRX-A6 elements with reactor corrosion performance indicates a successful correlation of corrosion test results with reactor results. Further, the corrosion test results indicate that two and perhaps more cycles could be tolerated for a total of 60 minutes of operating time at NRX conditions.

3.0 FUEL PERFORMANCE

(U) The principal measure of NERVA fuel performance is its resistance to reaction with the hydrogen coolant, called corrosion by analogy to more conventional reactor technology. The significance of fuel corrosion lies both in its effect on the structural integrity of the core and in its effect on the reactivity of the core. The corrosion-caused reactivity change is a function of both the loss of fissile material and the loss of moderator.

3.1 REACTIVITY CHANGE

(CRD) The initial indication of fuel corrosion resistance in a NERVA reactor test is the degree of rotation of the control drums needed to counteract the in-core reactivity loss. The behavior of NRX-A6 in this respect was far superior to that of previous cores tested, as shown in Figure 3-1. The cumulative reactivity loss of NRX-A6 in a 60-minute test was only \$0.65, which was compensated by a control drum angle change, $\Delta\Theta$, of 11 degrees. This compares very favorably to reactivity losses and drum angle changes of \$3.21, 59 degrees and \$2.15, 38 degrees in the NRX-A4 (EST) and NRX-A5 reactor tests after 30 minutes of operation.

3.2 TOTAL WEIGHT LOSS

(CRD) Examination of individual fuel elements confirmed the indications of the low reactivity loss. The extent of fuel corrosion was much smaller than in previous reactor tests. The weight lost by fuel elements is shown in Figure 3-2 as a function of their positions in the cylindrically symmetrical core. The average weight loss per element was 13.2 grams, less than half the average amount lost in the two previous shorter reactor tests. The time rate of corrosion in NRX-A6 was about one-fifth that observed in NRX-A4 and NRX-A5.

(CRD) Of the average weight lost per element, an estimated 2 grams is attributed to the loss of molybdenum deposited over the niobium carbide coolant channel coating. The fraction of the Mo deposit which infiltrated the cracks in the NbC coating was found to be effective in decreasing corrosion. However, the Mo lost from the NbC surface was of little value. Thus, the effective average weight loss per element due to corrosion was more nearly 11.2 grams.

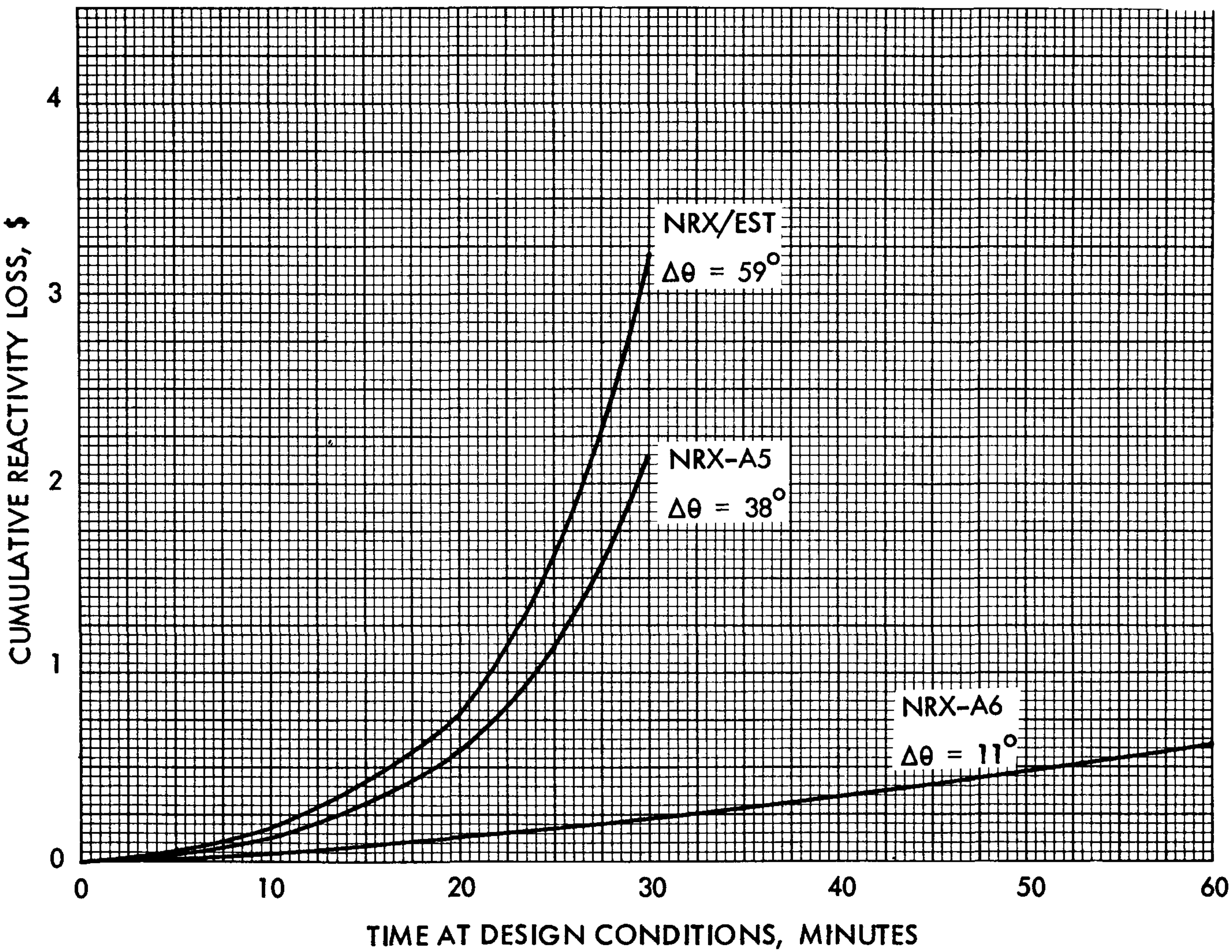

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Figure 3-1 (CRD) Variation of Cumulative Reactivity Loss with Time for the NRX-A4, NRX-A5, and NRX-A6 Reactors (U)

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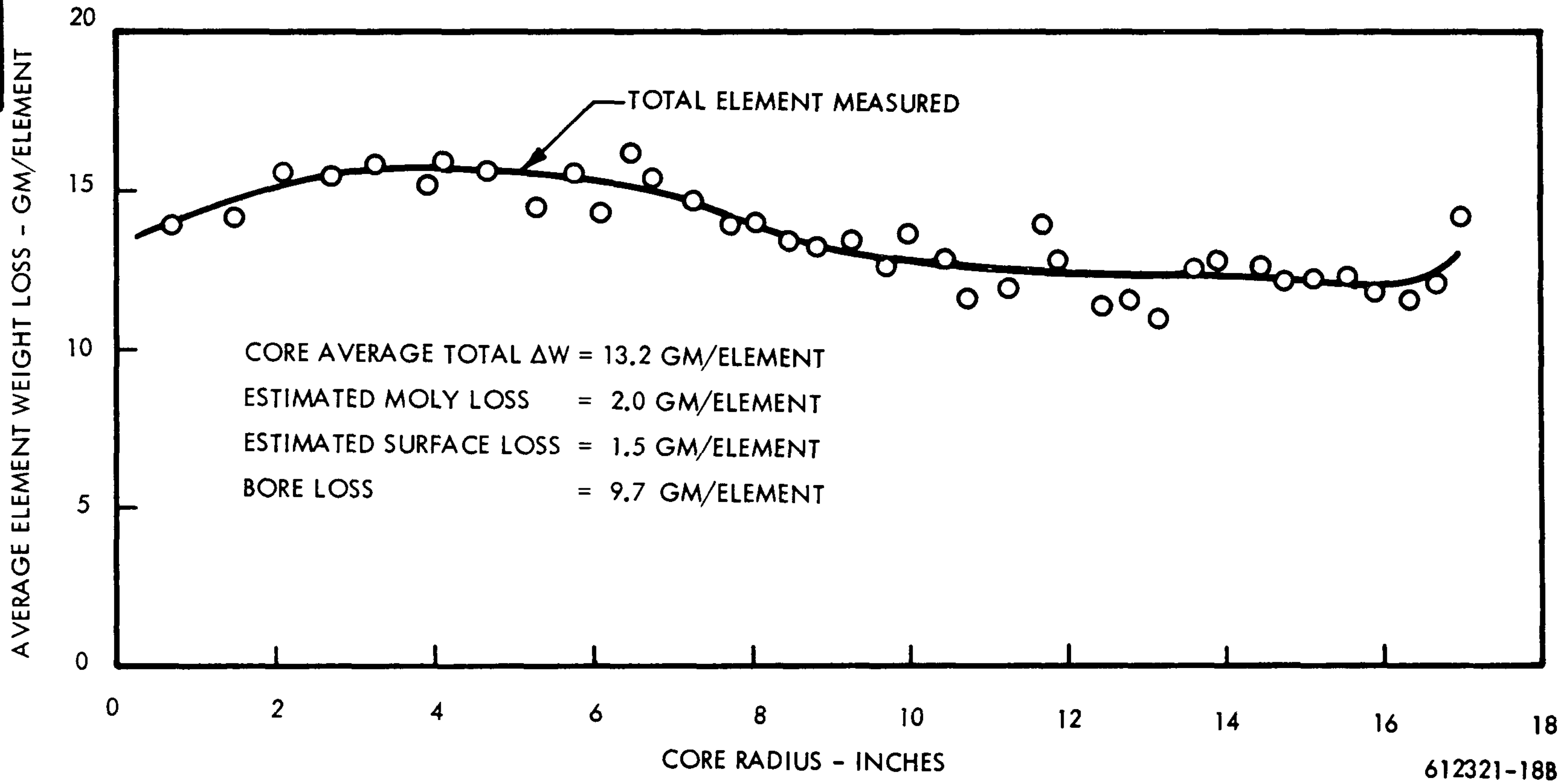

Figure 3-2 (CRD) NRX-A6 Fuel Element Weight Loss Versus Core Radius (U)

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3.3 INCREMENTAL WEIGHT LOSS

(CRD) The typical incremental weight loss curve characterizing NERVA fuel corrosion included a large maximum covering the core station 20 to 30 range, a fall-off to a relative minimum farther downstream and an increase again at the hot end. The fuel used in NRX-A6 eliminated the mid-band peak. The average weight loss of the upstream two-thirds of the fuel elements (stations 0 - 35) was about 2 grams, on the order of one-fifth of the total weight loss. Data illustrative of this behavior are shown in Figure 3-3.

(CRD) The mid-band and hot-end incremental weight losses observed in the NRX-A6 reactor test fuel elements were similar to those obtained from NRX-A6 elements tested electrically. Limited metallographic studies have shown a remarkable similarity in coolant channel corrosion characteristics for the two types of tests.

(CRD) The superior corrosion resistance of the fuel in the mid-band region as shown in the reactor test confirmed pre-test predictions of fuel performance. These improvements are largely attributed to changes in coating technique since the production of NRX-A5. These changes included deposition of a thinner coating to achieve a smaller crack size and the use of a lower NbC deposition temperature to decrease the thermal contraction mismatch and consequently the number of cracks. In addition, molybdenum was deposited over the NbC to fill the cracks.

3.4 SURFACE CORROSION

(CRD) Surface corrosion effects were also small in NRX-A6 as compared to NRX-A4 and NRX-A5. This has been attributed to a tight, uniform element bundling and to superior corrosion resistance of the fuel elements. Paradoxically, these characteristics enhanced interstitial pyrocarbon deposition and interelement bonding which caused fuel element breakage during disassembly. However, of the 234 elements broken, only about 18 were broken at positions of severe corrosion.

(CRD) Typical surface corrosion profiles are shown in Figure 3-4. Note the positive deviations from the original surface due to pyrocarbon and soot deposition as well as the negative deviations due to corrosion. This explains the banded structure seen across the fuel elements in Figure 3-5 in the partially disassembled core.

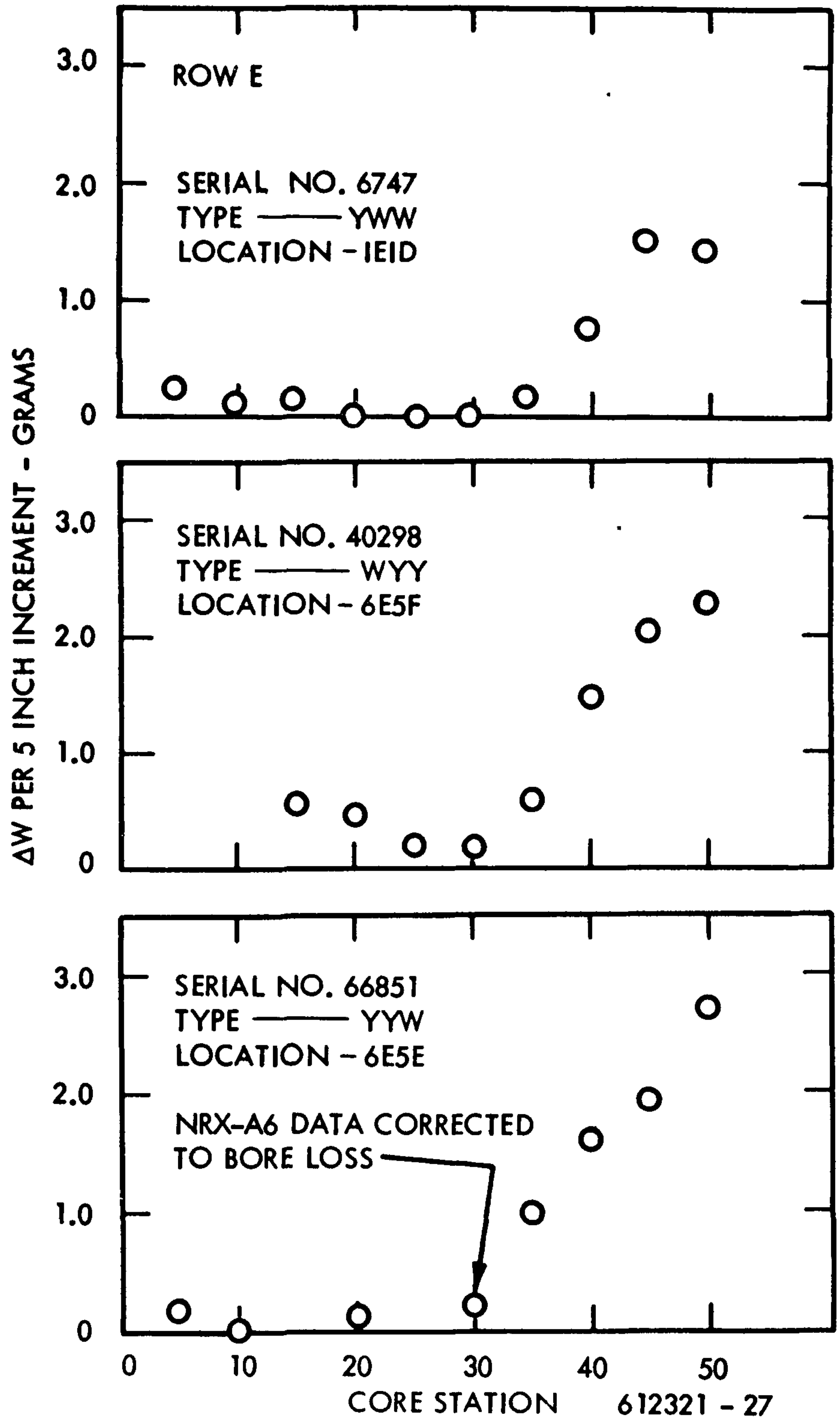

Figure 3-3 (CRD) Measured Incremental Weight Loss for Typical NRX-A6 Fuel Elements (U)

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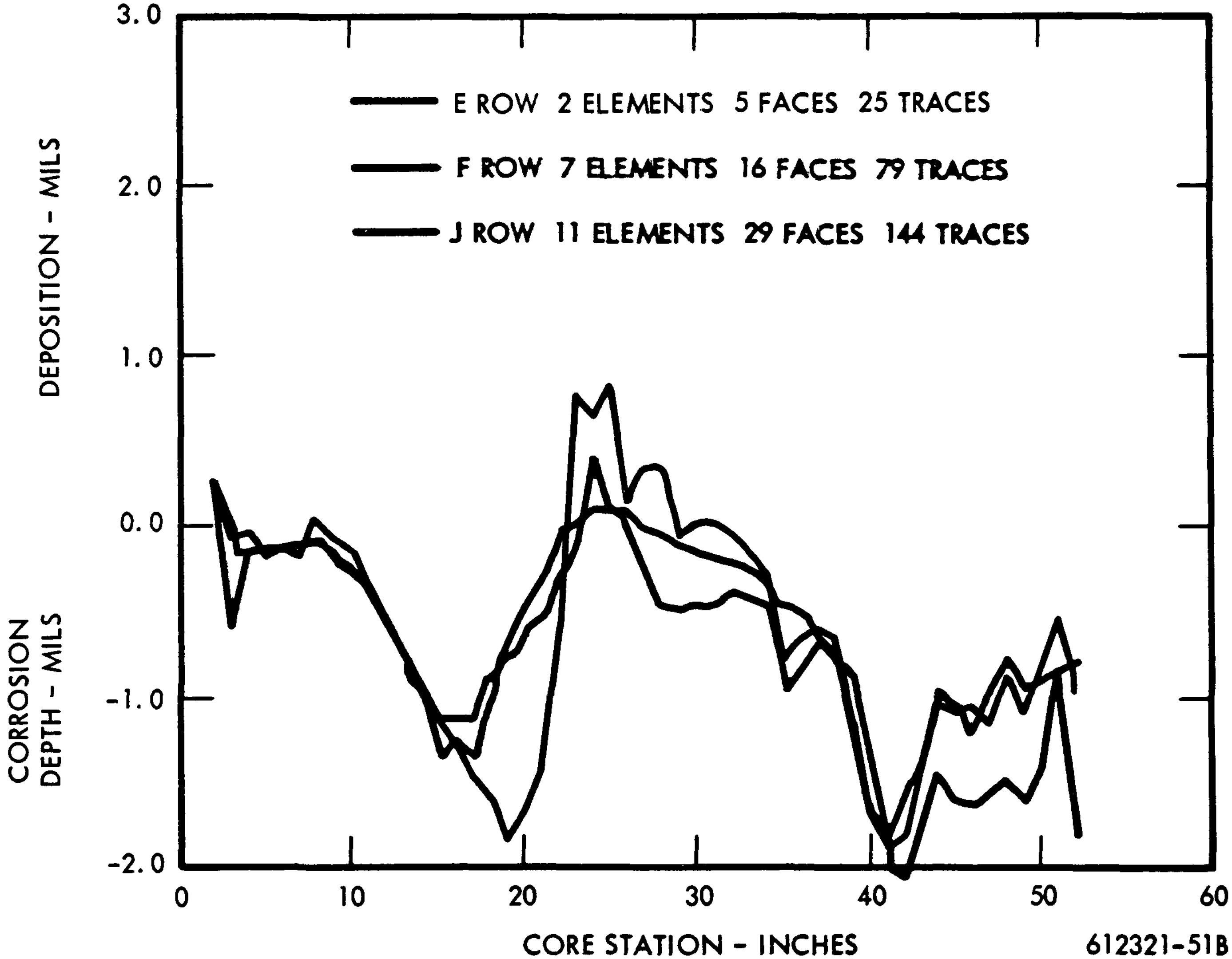

Figure 3-4 (CRD) Post-Test Surface Profiles of NRX-A6 Fuel Elements (U)

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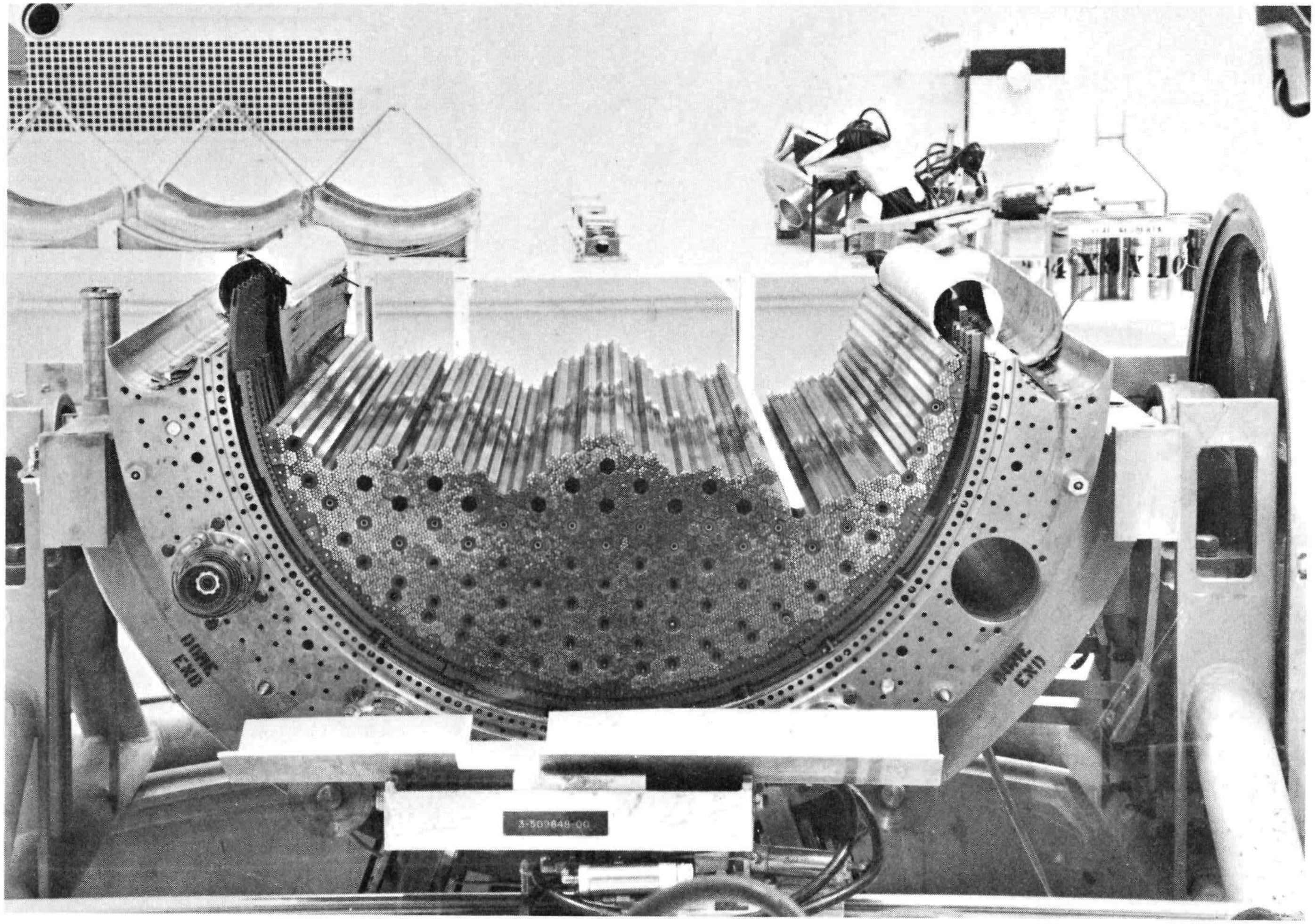

Figure 3-5 (CRD) NRX-A6 Core During Post-Test Disassembly (U)

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3.5 PINHOLES

(CRD) Pinhole and channel exposure occurrences in NRX-A6 elements as shown in Figure 3-6 were five to ten times less frequent than observed in NRX-A4 and NRX-A5. The axial distribution of pinholes is shown in Figure 3-7 where the data points are averaged over a large number of elements.

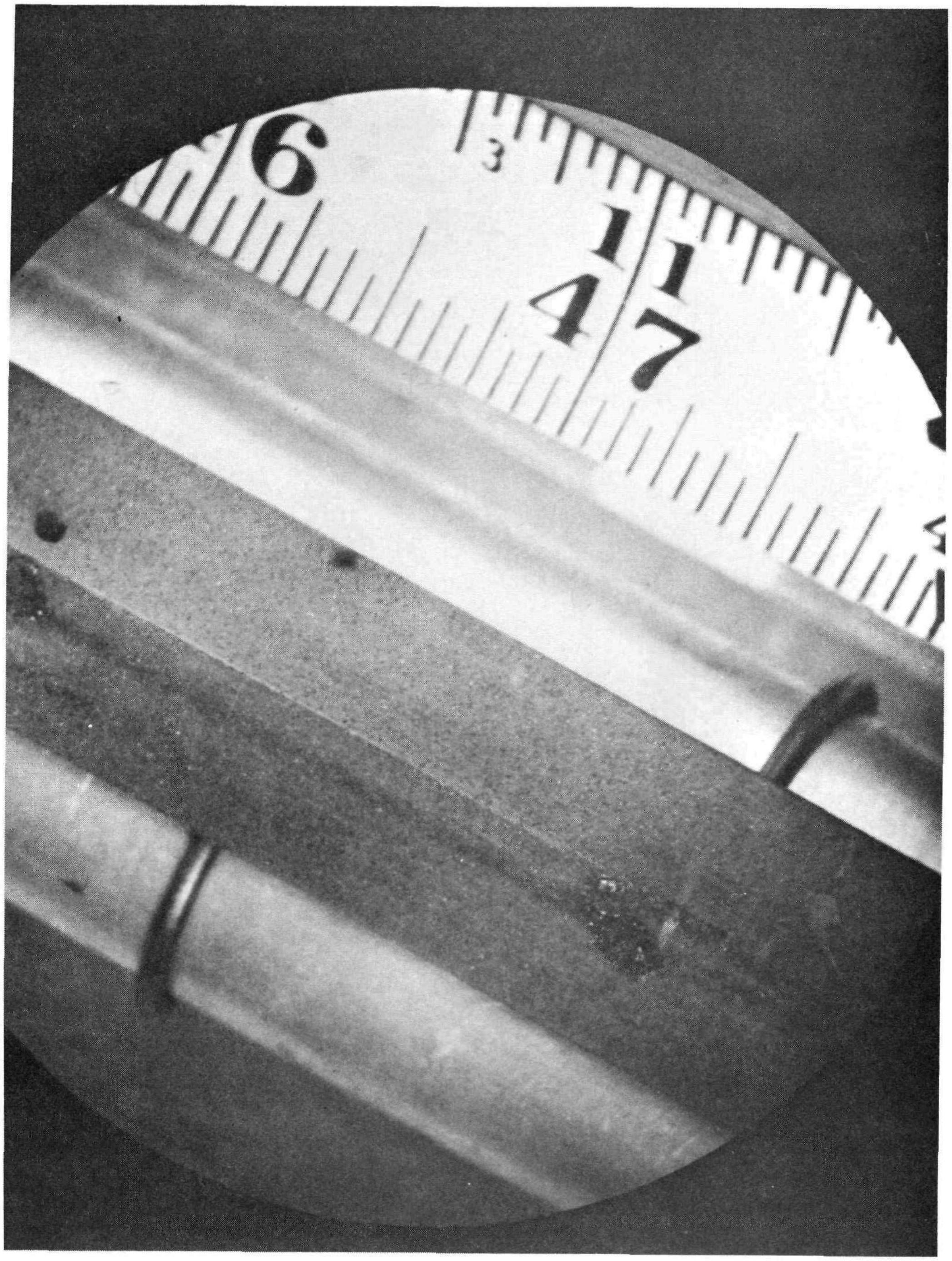

Figure 3-6 (CRD) Pinholes and Dimples at the Surface of NRX-A6 Fuel Element (U)

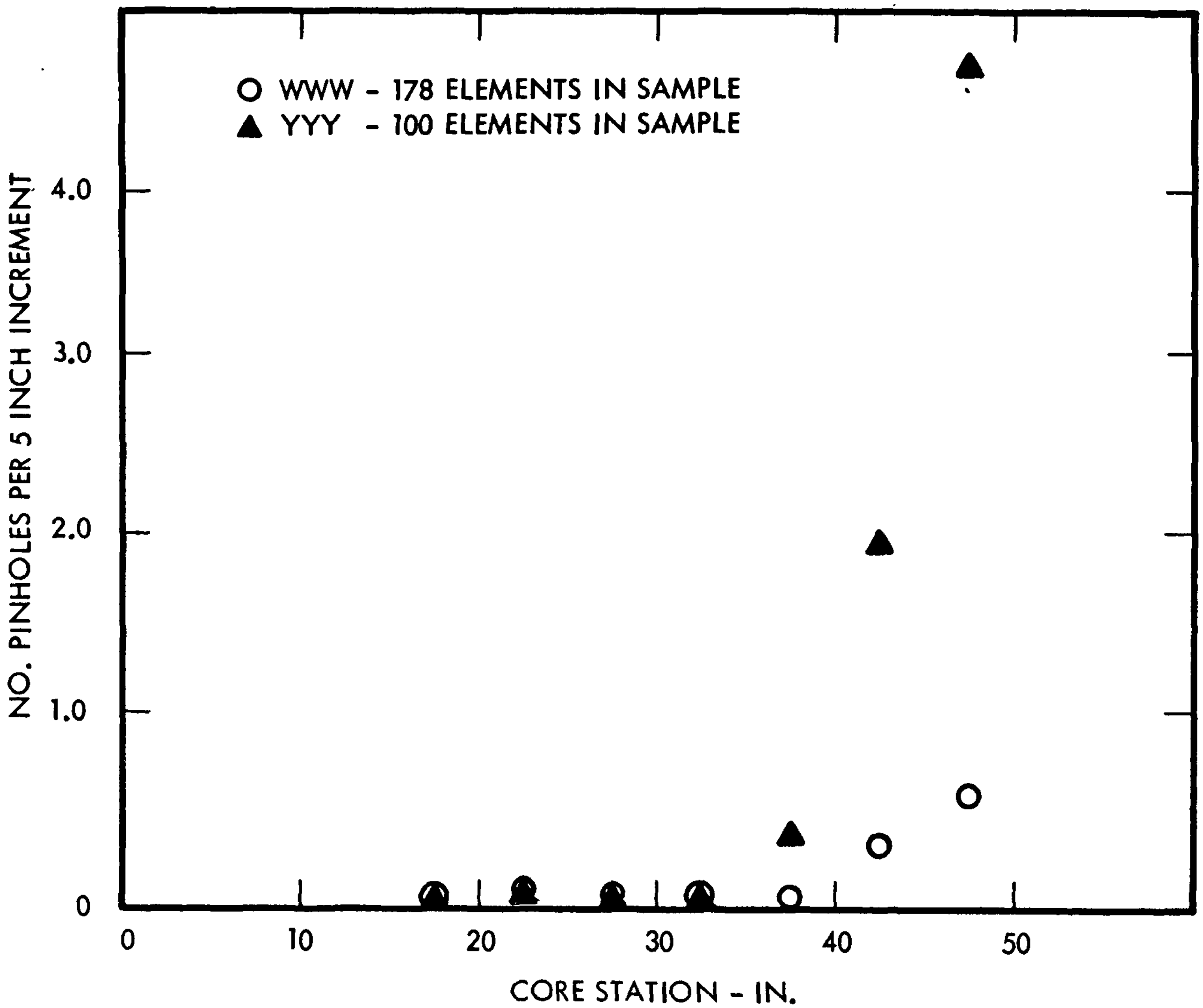

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Figure 3-7 (CRD) NRX-A6 Axial Distribution of Holes, Pinholes, and Dimples (U)

4.0 CONCLUSIONS

(CRD) The NRX-A6 reactor test demonstrated the capability of NERVA reactors to operate for 60 minutes at or above design conditions of 2050°C gas exit temperature and 1120 Mw power.

(U) The key NRX-A6 nuclear and thermal parameters measured at full power agreed well with predictions.

(CRD) The reactivity loss from the NRX-A6 core during the 60 minutes of operation at full power was 65 ¢ (compensated by a control drum rotation of 11 degrees), which was a great decrease in corrosion loss from the core in comparison with prior nuclear rocket tests.

(U) Examination of the corrosion of individual fuel elements confirmed the conclusion drawn in regard to the basis of reactivity loss: fuel element resistance to corrosion was superior.

(U) All of the NRX-A6 reactor test objectives were successfully accomplished.